U.S.–China Clean Energy Research Center
中美清洁能源联合研究中心

ANNUAL REPORT 2014-2015

And Review of CERC Phase 1

A Groundbreaking Bilateral R&D Partnership

In November 2009, U.S. President Barack Obama and China's former President Hu Jintao launched the U.S.-China Clean Energy Research Center (CERC) as a joint initiative to accelerate the development and deployment of clean energy technologies. Bringing together the two largest economies, each with world-class research and academic centers, CERC enables and encourages collaboration and innovation to speed progress toward a global clean energy economy. Teams of CERC scientists and engineers jointly plan and carry out collaborative research and development (R&D) activities that leverage the complementary strengths of each country.

CERC benefits both countries as a platform for tapping top-level talent at internationally distinguished research institutes, universities, and companies; leveraging valuable technical assets; and accessing major U.S. and Chinese markets. CERC provides a unique, jointly developed framework for protecting and sharing intellectual property. It is backed by both the U.S. and Chinese governments, encouraging researchers to offer their best ideas and engage in innovative thinking. In CERC's first five years (2011–2015), the two countries together invested $150 million in the R&D initiative—with U.S. government resources supporting U.S.-based entities and Chinese government resources supporting Chinese-based entities.

In November 2014, U.S. President Barack Obama and China President Xi Jinping formally recognized CERC's success in spurring advancements in clean energy technology and jointly announced the extension of CERC for the next five years (Phase 2, 2016-2020). For this second phase, the two countries agreed to continue CERC's three existing consortia—building energy efficiency, clean vehicles, and advanced coal technologies—and added a new consortium on the nexus of energy and water. In September 2015, the two Presidents announced a fifth consortium on improving the energy efficiency of medium-duty and heavy-duty trucks. CERC's Phase 2 will invest $250 million over five years with equal contributions from both countries.

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Message from the Directors

In January 2011, consortia leaders of the newly formed U.S.-China Clean Energy Research Center (CERC) gathered in Washington, D.C., to sign the first joint work plans. Together, they set off on a unique collaborative endeavor that was filled with promise—yet tempered by uncertainty regarding outcome.

Five years later, participants may now look back on this opening of Phase 1 with a sense of pride and satisfaction in all that has been accomplished. CERC undertook dozens of research projects of mutual interest to both countries. It grew to engage more than 150 public and private partners and more than 1,100 researchers.

In time, CERC participants achieved dozens of research outcomes of technical significance, filed patent applications and invention disclosures, and launched commercial products—some of which have received prestigious awards. Both countries made groundbreaking progress by enabling joint research through a novel approach to protecting and exploiting intellectual property.

Research professionals formed strong bilateral relationships based on friendship, trust, and mutual respect. The success of CERC as a bilateral model may have contributed, indirectly, to the achievement of a number of important diplomatic outcomes on energy and climate, as both Presidents have recognized in multiple joint statements on climate change.

Now, as the first phase of CERC draws to a close and a new phase begins, we look forward to working within a renewed and expanded charter. CERC will continue its original three tracks on advanced coal technology, building energy efficiency, and clean vehicles—and will expand to embrace two more tracks, one on the energy-water nexus and the other on improving the efficiency of medium- to heavy-duty trucks. We look forward with anticipation to helping CERC reach new heights.

Accordingly, this report sits at an inflection point in CERC's evolution. It both reflects on the past, with a focus on the 15-month period ending in December 2015, and looks to the future, laying out plans for CERC's next phase.

Specifically, we are pleased to share highlights on:

- **Phase 1 Accomplishments** that accelerate technology development, strengthen bilateral engagement, improve IP protection, and expedite market uptake of low-carbon technologies
- **2014–2015 Accomplishments** in each of the three existing CERC consortia—advanced coal and carbon capture technologies, energy-efficient buildings, and clean vehicles—and the planning milestones achieved for the two new consortia—the energy-water nexus and more efficient medium- and heavy-duty trucks and related technologies
- **Phase 2 Plans** for CERC for the period 2016-2020 for all five tracks

CERC owes its success to its technical leaders and their research teams. We salute their creativity, hard work, and commitment to working collaboratively and successfully across distances, cultures, and languages to fulfill the vision of our Presidents. Innovation in clean energy will move both nations toward a more prosperous, clean, and energy-efficient future.

Dr. Robert C. Marlay, Ph.D.
CERC Director for the United States
U.S. Department of Energy

Cai Jianing
Associate Counsel, Department of International Cooperation
China Ministry of Science and Technology

CERC's Collaborative Framework Leverages Resources

54
U.S. Partners*

110
Chinese Partners*

284
U.S. Researchers

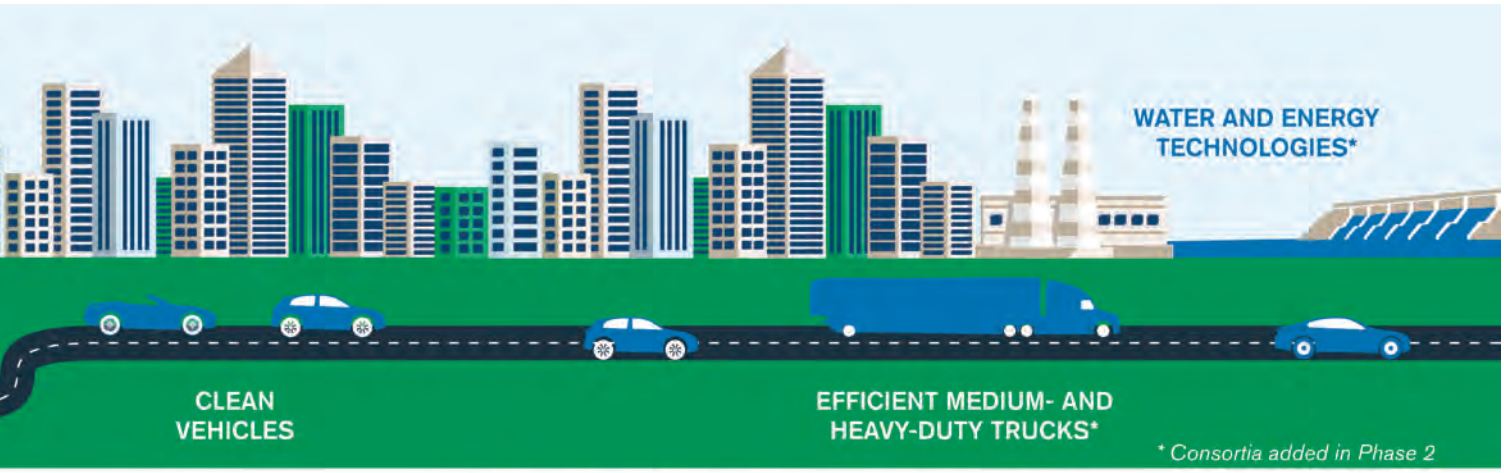
840
Chinese Researchers

$75M
From U.S. Government and Partners

$4.5M
Investment by U.S. Partners Above Initial Commitment

$75M
From Chinese Government and Partners

** For Phase 1. As of June 2016, CERC has a total of 82 U.S. Partners and 123 Chinese Partners*



Phase 1 Accomplishments

Technological

44
Significant Research Outcomes*

39
Invention Disclosures and Patent Applications Filed

* For details, go to www.us-china-cerc.org

Environmental

275M
Tons of CO_2 Emissions Avoided/Year by 2025*

(More than current emissions from the Netherlands)

* Does not include projected additional benefits from Phase 2

Diplomatic

High-level Commitment from leaders of both countries has resulted in

7
Significant Cooperative Bilateral Outcomes*
attributed, in part, to CERC

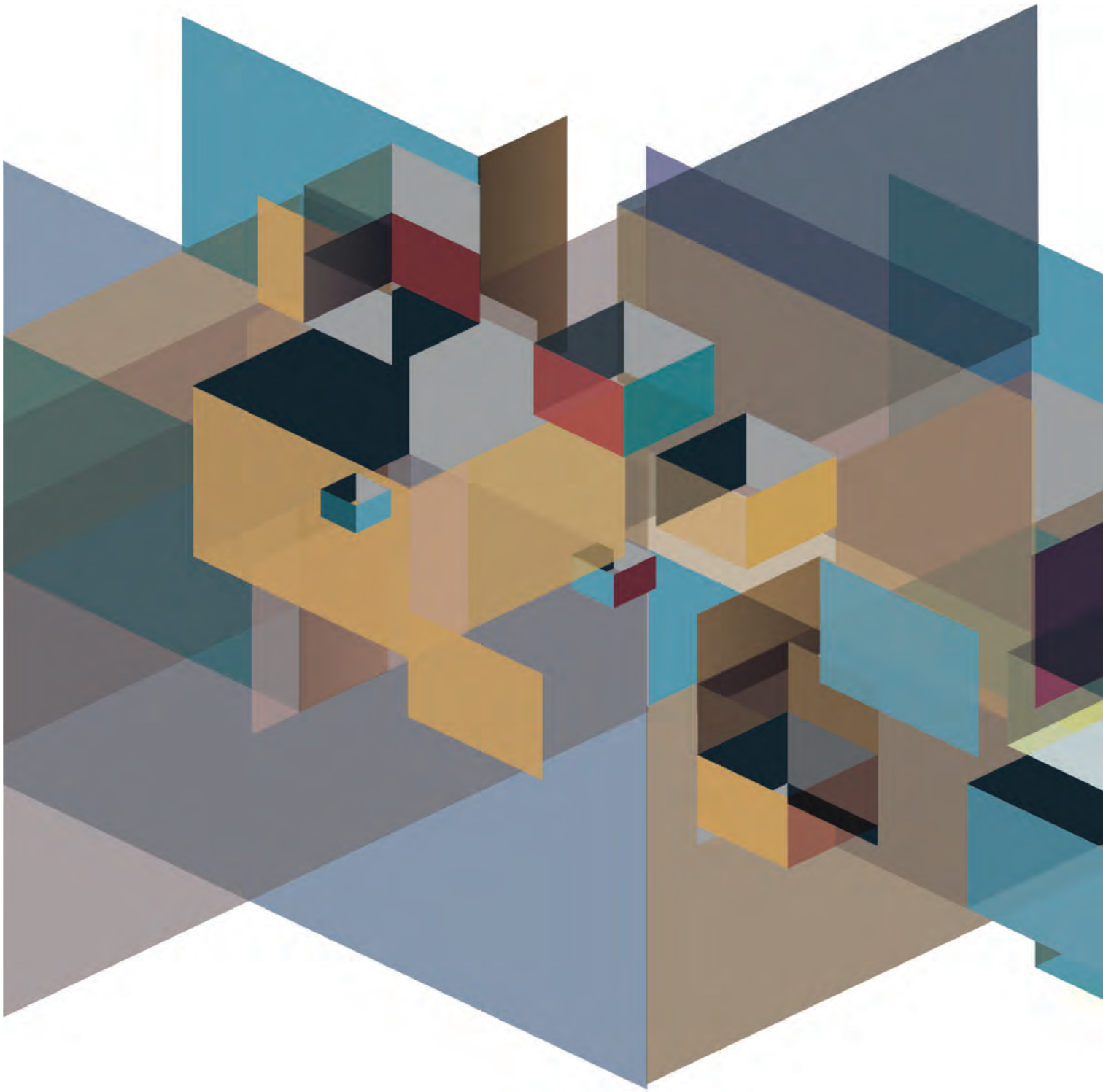
* For details, see page 14

Economic

10
Demonstrations

15
Products Launched

CERC provides its partners **Increased Market Access** to large economies—
Offering Broad Economic Benefits



Phase 1 (2011-2015): A Productive New R&D Partnership

The first phase of CERC established a successful bilateral research partnership in clean energy. It is built on a robust foundation centered on CERC's four overarching goals:

- **Accelerate Development and Deployment of Clean Energy Technologies**. By leveraging complementary talent and resources, both countries are meeting their economic, energy, and climate goals faster and more affordably.
- **Expand and Strengthen U.S.-China Bilateral Engagement.** High-level commitments by both governments are enabling joint R&D in cutting-edge technologies and delivering diplomatic benefits.
- **Protect IP, Encourage its Development, and Improve U.S.-China Interactions Regarding IP.** CERC's framework for protecting IP fosters an environment in which innovation can flourish.
- **Facilitate Relationship Building and Market Access by Businesses to Speed Technology Deployment.** CERC partnerships take innovations from primary research to the global marketplace—where technologies deliver clear economic and climate benefits.

Phase 1 achievements in each of these four areas are summarized briefly in the following subsections.

Phase 1 (2011-2015): A Productive New R&D Partnership

Accelerate Development and Deployment of Clean Energy Technology

The United States and China formed CERC to help meet their respective national clean energy and climate goals and capture related economic benefits. Clean energy solutions help both countries tap diverse energy sources, improve energy efficiency, and accelerate the global transition to a low-carbon future. As leading developers of clean energy technology, the United States and China simultaneously foster economic growth at home and boost competitiveness in global markets.

In its first phase, CERC made significant progress delivering technology solutions for each of its three consortia:

- Advanced Coal Technology
- Building Energy Efficiency
- Clean Vehicles

Through CERC, leading scientists, engineers, and industry experts from each country were able to come together and find clean energy solutions more quickly and efficiently than could teams of either nationality working alone. Joint U.S.-China research projects discovered cutting-edge technologies to improve building envelopes, explored thermoelectric materials to utilize waste heat in vehicles, improved investor confidence in CO_2 capture technologies, and advanced numerous other clean energy technologies for buildings, vehicles, and clean coal. Highlights of selected technical outcomes from each consortium during CERC Phase 1 are presented on the following pages.

44
SIGNIFICANT RESEARCH OUTCOMES

323
PEER-REVIEWED PUBLICATIONS

8
SOFTWARE COPYRIGHTED WORKS

By prioritizing scientific innovation and fostering the discovery of new technologies, CERC is helping the two largest global economies meet their clean energy goals while also generating new business streams for private industry.

Advanced Coal Technology Consortium (ACTC)

Advancing cost-effective post-combustion CO_2 capture technologies

Equipping coal power plants with CO_2 capture technologies can enable large-scale emissions reductions, as required to meet bold climate goals. Currently, these technologies are cost-prohibitive and tend to lower plant efficiency. In addition, the lack of adequate cost data and in-plant demonstrations creates uncertainty in the market. To address these deficiencies, CERC researchers from Lawrence Livermore National Laboratory (LLNL) and Huaneng conducted a conceptual simulation of a post-combustion CO_2 capture system in Duke Energy's Gibson-3 station in Indiana, using technology developed by Huaneng and demonstrated at its Shanghai Shidongkou power plant. Under the CERC framework, both U.S. and Chinese plants provided operating and cost data for this study—considered groundbreaking in U.S.-China bilateral R&D. The simulation indicated that if the same system were to be installed at Duke Energy's Gibson-3 plant, the cost would be much lower than previously thought: about US $61–$68 per metric tonne of CO_2 versus previous estimates of US $100 per metric tonne. Cost data like this could help speed deployment of CO_2 capture technologies in existing coal plants.

China Partner: Huaneng

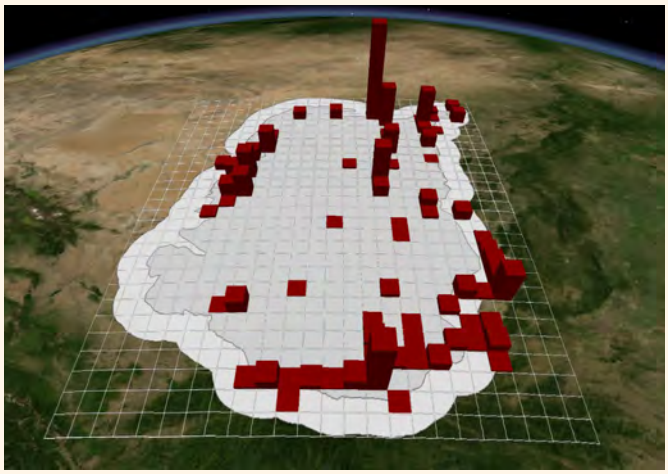
U.S. Partners: Duke Energy, LLNL

Examining low-cost solutions for oxy-combustion technologies

Oxy-fuel combustion is a promising technology with the potential to reduce the cost of downstream CO_2 capture. Full-scale implementation of oxy-fuel combustion technologies is limited by high capital costs and reduced plant efficiencies. Developing cost-effective oxy-fuel combustion systems requires a clear understanding of coal combustion characteristics under various conditions. This understanding supports more accurate estimates of performance and costs, particularly when using computational fluid dynamics (CFD) models. To address this need, CERC researchers from Huazhong University of Science and Technology (HUST) and Babcock & Wilcox Company jointly investigated fundamental reactions for eight types of coal (four from each country) under oxy-firing conditions and developed CFD models for U.S. and China pilot-scale test facilities. Researchers engaged in a truly collaborative manner by creating a data exchange mechanism early in the study. Results indicate improved performance and lower costs. Once the models have been validated in larger-scale demonstration projects, they are expected to facilitate the technology's deployment in a variety of coal regions around the world in the presence of supportive policies.

China Partner: HUST

U.S. Partner: Babcock & Wilcox Company

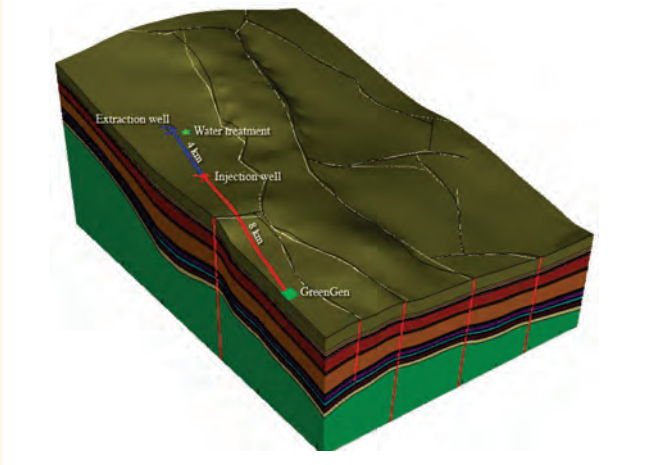


Evaluating the potential for CO_2 storage in enhanced oil recovery

Enhanced oil recovery (EOR) methods commonly used in the oil and gas sector have the potential to enable geological storage for significant amounts of CO_2. CERC researchers conducted a feasibility study of EOR potential in the Ordos Basin of China, a region that provides affordable, capture-ready CO_2 sources and large-scale EOR projects. Since China's Ordos Basin is geologically similar to Wyoming's Powder River Basin, CO_2 storage strategies adopted in Wyoming may be applicable in the Ordos Basin. Building on the complementary expertise of the U.S. and Chinese teams, researchers constructed a comprehensive database that includes geochemical, petro-physical, structural, and other data for assessing EOR potential in the Ordos Basin. The team then tested, simulated, and optimized an integrated energy/carbon capture, utilization, and storage (CCUS) strategy developed by the University of Wyoming for the Powder River Basin for various EOR scenarios in the Ordos Basin. The simulation shows that integrating EOR with CO_2 storage is a viable way to reduce CO_2 emissions in the region.

China Partners: Chinese Academy of Sciences, Shaanxi Provincial Institute for Energy Resources and Chemical Engineering, Yanchang Petroleum Company

U.S. Partners: University of Wyoming Carbon Management Institute



Assessing the CO_2 storage potential in deep, saline aquifers

Geological storage of CO_2 combined with deep saline water recovery has the potential to store massive quantities of CO_2 while simultaneously enabling use of the extracted water. CERC researchers conducted a prefeasibility study to analyze CO_2 storage potential at GreenGen, an integrated gasification combined cycle (IGCC) power plant in Tianjin, China, where Huaneng is completing construction of its CO_2 capture system. The CERC team identified geological conditions, plant requirements, and costs. Initial prefeasibility results are promising. The study found that storage capacity exists in the region, the withdrawn water can realistically be treated for use in the power plant and other applications, and reservoir properties in the region are suitable. Average operating costs for treating the formation water are estimated to range between US $2.37 and $2.92/$m^3$. In the long term, a more detailed study could help to ease a cumbersome injection permitting process and further evaluate the feasibility of enhanced water recovery (EWR) technologies.

China Partner: Huaneng

U.S. Partners: Indiana Geological Survey, Los Alamos National Laboratory, LLNL, University of Wyoming, West Virginia University, World Resources Institute

Building Energy Efficiency (BEE) Consortium

Accelerating window and shading technologies that deliver significant energy savings

Advanced window and shading technologies can cut electricity demand for lighting and for heating, ventilation, and air conditioning (HVAC)—saving energy and reducing emissions. CERC researchers found that low-emittance windows with adjustable shading could reduce HVAC electricity use by up to 66% around building perimeters. Through modeling, laboratory tests, and field studies, researchers demonstrated cost-effective performance for three complementary technologies: advanced switchable electrochromic windows, dimmable lighting, and low-energy cooling strategies. To analyze energy savings in an integrated, full-building microgrid, researchers developed software to optimize window and lighting operation in conjunction with onsite photovoltaics and energy storage, accounting for human factors like glare. In simulations, this integrated software reduced energy usage 10% compared to existing control systems. Based on these findings, the Ministry of Housing and Urban-Rural Development (MOHURD) agreed to adopt ISO 15099, which specifies procedures for determining thermal and optical transmission properties of windows, and a Chinese version of Lawrence Berkeley National Laboratory's (LBNL's) WINDOW 6 software was released.

China Partners: Chongqing University, Saint Gobain (Shanghai), Tongji University

U.S. Partners: 3M, Dow Chemical, LBNL, Lutron Electronics Inc., Saint Gobain, Sage Electrochromics

Saving energy with high-performance cool roof materials

Solar-reflective cool roofs can be one of the most economical retrofit approaches for managing temperature, conserving energy, and reducing emissions. Simulations reveal that widespread adoption of cool roofs could significantly lower afternoon air temperatures in the hot and populous city of Guangzhou, China, especially during heat waves. A key challenge to increasing the use of cool roofs is the durability of coatings. CERC researchers developed an environmentally friendly, anti-soiling roof coating. Accelerated testing demonstrated its long-term durability, enhanced water repellency, and soil resistance. Research institutes and laboratories in both countries are evaluating the product's performance as the basis for a Chinese roof rating program to accelerate market penetration. The project has led to new Chinese standards and credits for the use of cool roofs in some climates.

China Partners: China Building Material Test & Certification Group; Chinese Academy of Sciences; Chongqing University; Guangdong Provincial Academy of Building Research; Institutes of Building Research (IBRs) from Shenzhen, Xiamen, Jiangsu, Sichuan, Shangxi, and Xijiang; MOHURD Research Institute of Standards & Norms

U.S. Partners: Dow Chemical, LBNL, Oak Ridge National Laboratory (ORNL)

Developing more energy efficient and lower cost ground source heat pumps

Ground source heat pumps (GSHPs) are more energy efficient than conventional space conditioning and water heating systems, yet this technology has penetrated only 1% of U.S. and Chinese markets. The key barrier in the United States is high initial cost; in China, it is the lack of standards. CERC researchers teamed with industry to identify a new ground heat exchanger (GHX) that requires 14%–30% less drilling and associated cost than conventional GHX. Researchers also developed (1) a new analytic tool for cost effectively monitoring the performance and detecting faults in distributed GSHP systems and (2) an innovative flow-demand-based control to reduce pumping energy by 20% or more. A first-of-its-kind, flexible research platform was built and used to evaluate the new controls for central pumping of distributed GSHP systems and water heating of a ground source integrated heat pump. A distributed GSHP system was demonstrated at the China Academy of Building Research (CABR) in Beijing.

China Partners: CABR, Chongqing University, Tianjin University, Tongji University

U.S. Partners: ClimateMaster, ORNL

Using demonstrations to evaluate innovative building technologies in integrated systems

In true collaborative spirit, CERC researchers teamed with industrial partners to demonstrate new technologies in buildings in China and the United States. Some of the most significant demonstration projects are being undertaken in China at the CABR in Beijing and the Xing Ye Research and Office Building in Zhuhai, China. CERC technologies being demonstrated at CABR include GSHPs, lighting controls, and air barriers. These technologies and others contributed to significant reductions in energy use and emissions at CABR: a 50% reduction in cooling energy, a 75% reduction in lighting energy, and zero fossil fuel use in space heating. The newly constructed Xing Ye building is setting new standards in energy efficiency with a 76.7% energy savings target (compared to 1980 levels) and a 14.4% share of renewable energy. These demonstrations contributed to the development of China's first very low energy building standard.

China Partners: Beijing University of Construction and Architecture, Tianjin University, Tongi University, Wuhan Rixin, Xing Ye Solar

U.S. Partners: C3, LBNL, Lend Lease, Saint Gobain, Sage Electrochromics, Walt Disney Imagineering

Clean Vehicles Consortium (CVC)

Developing high-energy-density battery chemistries for electric vehicles

New battery chemistries that provide higher energy density could revolutionize electric vehicle (EV) markets—enabling affordable EVs that travel several hundred miles on a single charge. In contrast, standard lithium-ion battery chemistries in current EVs offer limited opportunities to improve performance, cost, or efficiency.

In Phase I, CERC researchers made significant advances in high-density battery technologies that could lead to smaller, lower-cost EV batteries with higher capacities. Research produced computational tools and models to identify and characterize the mechanisms limiting performance in some promising, high-energy-density chemistries—primarily lithium-air, lithium-sulfur, and sodium-air. In parallel, CERC researchers characterized various lithium-sulfur (solid electrolyte) compositions, improving current understanding of key degradation mechanisms. Most recently, the team investigated sodium-air battery chemistries, providing new insight into how they deliver higher efficiencies. CERC researchers are helping to make long-range, affordable EVs a reality through activities like these, which appear in academic papers and journals.

China Partners: Beijing Institute of Technology, Tsinghua University

U.S. Partners: Argonne National Laboratory, Denso, University of Michigan

Developing off-line and on-board EV battery health management

Accurately assessing the state of health (SOH) of lithium-ion battery systems is a crucial challenge. CERC research teams developed off-line and on-board SOH assessment techniques for these promising battery systems. The techniques are able to obtain a range of critical measurements to diagnose SOH. Specifically, the techniques can (1) quantify the capacity degradation of the cathode and anode using a mechanistic model off-line; (2) estimate SOH based on incremental capacity analysis on-board; and (3) analyze interactions between different cells within a battery pack during capacity degradation to determine the effects of cell non-uniformity due to manufacturing. These SOH diagnostics have been applied in simulation and used with a real battery management system manufactured by KeyPower for a battery electric logistic vehicle.

China Partners: KeyPower, Tsinghua University

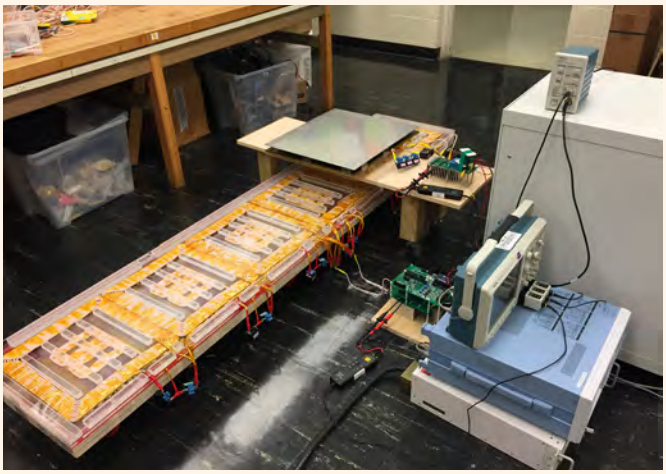
U.S. Partner: University of Michigan

Converting vehicle waste heat into energy using efficient thermoelectric materials

Recovering energy from vehicle engine exhaust could improve overall fuel economy by more than 5%. CERC researchers jointly developed a novel approach for fabricating bulk thermoelectric materials, which can be used to convert waste heat from cars and trucks into electricity. The approach uses self-propagating, high-temperature combustion synthesis (SHS). The research community had believed that SHS requires temperatures above 2073˚C, but CERC research shows that it can be used to synthesize lower-melting-point materials. CERC researchers developed and published a new criterion for the applicability of SHS to a wider range of materials. This research opens a new avenue for ultra-fast, low-cost, and large-scale production of thermoelectric materials. Researchers applied the novel SHS approach to a variety of thermoelectric materials to determine material properties and operating behavior. The resulting data has helped to optimize the performance of several thermoelectric compounds, accelerating the possibility that thermoelectric devices may be used to improve vehicle efficiency in the near future.

China Partner: Wuhan Institute of Technology

U.S. Partners: ORNL, The Ohio State University, Sandia National Laboratory, University of Michigan



Charging electric vehicles wirelessly with higher efficiency

The ability to quickly recharge EVs wirelessly could accelerate a global transition to a lower-carbon, more efficient transportation system. CERC researchers developed a method to wirelessly charge electric vehicles with greater efficiency and controllability than existing systems. It automatically tunes the resonance so that neither the efficiency nor the rate of charging degrades excessively when the car and charging plate are misaligned or farther apart than the optimal distance. The method's direct current (DC)-to-battery efficiency exceeds 96% at 7.7 kW of output power. The team built prototypes for 7.7kW and 3.3kW wireless systems to test in an automotive environment (based on Society of Automotive Engineers standard requirements). Researchers also built a series of higher frequency, low-cost, smaller-size systems to assess their operation. These high-frequency systems maintained a 95% peak DC-to-battery efficiency. In addition, the team developed a 3.3 kW capacitive wireless transfer system tailored for dynamic roadway EV charging. This system provides stable and consistent power transfer with up to 92% efficiency at a lower cost and with increased tolerance for misalignment.

China Partners: Beihang University, Institute of Electrical Engineering Chinese Academy of Sciences, Tsinghua University

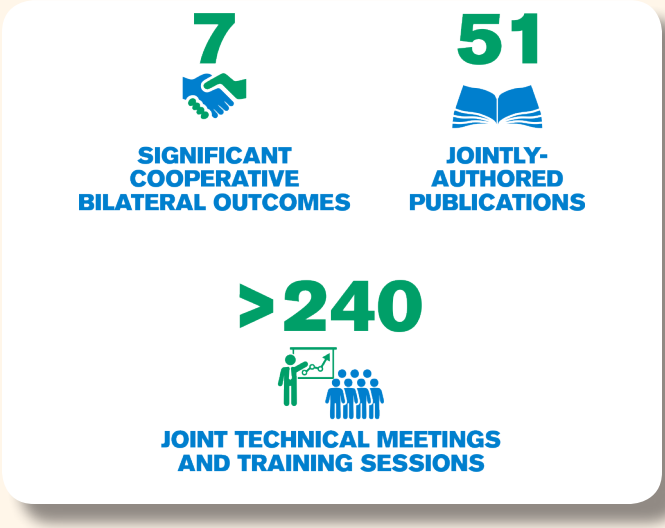
U.S. Partners: Denso, University of Michigan

Expand and Strengthen U.S.-China Bilateral Engagement

The U.S.-China bilateral relationship is one of the most consequential in the world today. As top energy producers and consumers, the two countries have vested interests in advancing innovative clean energy solutions, and both countries anticipate strategic and economic benefits from the global transition to clean energy. CERC harnesses the skills, expertise, and resources of the United States and China—providing a better, faster, and cheaper route to innovative clean energy technologies than either country is likely to achieve alone.

CERC simultaneously accelerates progress on critical technologies and helps build goodwill and trust between two of the world's most influential governments. CERC's platform for collaborative clean energy-related research is based on principles of equality, shared interests, mutual respect, friendship, and reciprocity. Unlike most other bilateral R&D partnerships that focus mostly on workshops and personnel or knowledge exchanges, CERC facilitates true collaboration among researchers by requiring them to develop joint plans and conduct research in close consultation with one another. By deepening relationships among leading researchers, CERC is gradually building trust at multiple levels, strengthening bilateral engagement between the two countries, and influencing the broader realms of diplomacy—as reflected in several high-level announcements by both countries in recent years:

- May 2013: At the U.S.-China Innovation Dialogue, Director-General Jin Xiaoming of China's Ministry of Science and Technology (MOST) recognized CERC as the "most successful China-U.S. energy cooperation program since normalization of relations in 1979."
- November 2014: In a joint announcement, the two countries renewed their commitment to CERC, extending its scope and duration for the next five years (2016–2020) and adding a track on the energy-water nexus. At the same time, the two countries jointly announced their climate change targets (intended nationally determined contributions or INDCs) one full year in advance of the Paris climate conference—generating momentum for a successful outcome the following year.



- March 2015 and June 2015: U.S. and China submitted their respective climate action plans to the United Nations Framework Convention on Climate Change.
- September 2015: The two countries jointly announced establishment of a 5th CERC track to improve the energy efficiency of medium- and heavy-duty trucks.
- November 2015: The United States and China joined 18 other countries in launching Mission Innovation, a pledge to double government investment in clean energy R&D over five years.
- December 2015: More than 190 countries agreed on a plan to address climate change at the successful Paris meeting, inspired, in part, by progress in clean energy innovation among emerging economies.

The remarkable recent progress by the United States and China on clean energy has been enabled, in part, by increased levels of trust and communication between senior-level U.S. and Chinese leaders. These improved relationships have been cultivated and strengthened through their participation in CERC.

CERC's success in generating innovative technologies and creating value is tied to its unique, truly collaborative framework: one that leverages the best minds, skills, and expertise of both countries and provides a robust IP platform that promotes the sharing of knowledge and creativity.

Protect IP, Encourage its Development, and Improve U.S.-China Interactions Regarding IP

Intellectual property (IP) must be adequately protected to enable true partnership in developing innovative technologies. Strong IP protections permit closer collaboration and enable researchers to share their best ideas and concepts.

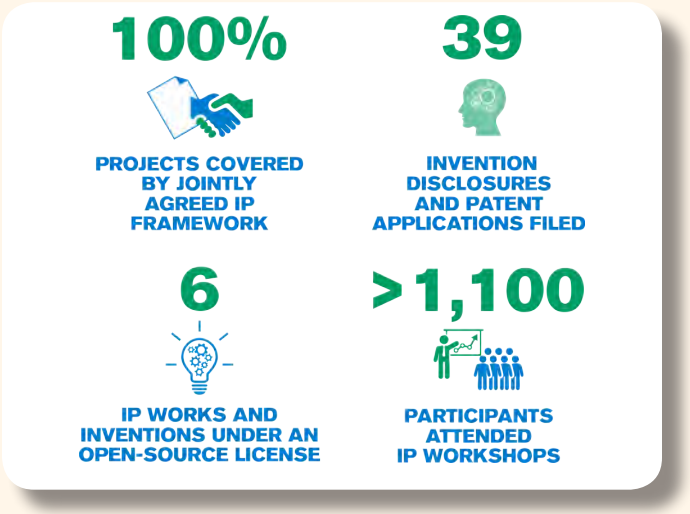
The CERC IP Protocol and accompanying IP Annex encourage innovation by enabling researchers to share knowledge and feel confident that their IP and new inventions will be lawfully protected. This IP framework, negotiated and agreed upon at the outset of CERC, helps R&D project participants identify and protect their rights in accordance with local laws and international standards.

Within each CERC consortium, the Protocol and IP Annex are supplemented by a Technology Management Plan (TMP) developed and endorsed by both governments for each consortium. These TMPs guide the development of project-specific contracts and provide a framework for the ownership and protection of IP rights, while also providing researchers the flexibility to negotiate contractual details as needed.

Both governments recognize the importance of IP and have agreed to monitor progress, hear issues, and intervene diplomatically, if warranted. CERC favors a collaborative approach to IP management, encouraging participants to anticipate the need for and execution of IP agreements in advance of research. To assist researchers in successfully negotiating IP issues, CERC provides a robust program of IP education, training, and technical assistance.

CERC's IP education and training program provides tools and resources to help researchers understand the CERC IP framework and relevant IP laws and practices in both the United States and China. Achievements over the first phase of CERC include the following:

- Established a joint IP experts group, including academics, practicing attorneys, and other experts in IP and clean energy technology transfer, to help researchers navigate the complex legal frameworks of the two countries. This group guides the IP program and provides ongoing support and assistance as needed.



- Organized four IP workshops with legal and policy experts from both countries. These workshops explored IP practice in the United States and China and ways the countries can work together to strengthen IP protection and manage IP in joint CERC research. The workshops provided platforms for knowledge and information exchange, enabled open and frank discussions, and addressed timely and relevant issues. The IP program's first pilot training session in Wuhan, China, gave participants useful information about the CERC IP framework and the IP legal processes in both countries.

- Crafted an annotated TMP to convey critical elements of CERC's IP framework to those without legal training. The annotated TMP offers detailed explanations of the meaning and implications of certain provisions of the TMP, and it outlines how to implement these provisions in specific projects.

- Published a bilingual *Researcher's Guide to IP and Technology Transfer*. Based on the University of Michigan guide and developed by lawyers and other IP experts in the United States and China, the *Guide* explains key IP issues in both countries in lay terms.

- Shared presentations and information from the workshops via a web portal (ipknowledge.org) to update interested parties on IP issues.

CERC is a recognized source of innovation and creativity, as indicated by its major technical accomplishments. Innovation is crucial for value creation: it translates into valuable intellectual property and is essential to sustain economic prosperity.

中美清洁能源联合研究中心（CERC）
中美联合知识产权培训
The Joint Training on Intellectual Property for the U.S.-China Clean Energy Research Center (CERC)

Facilitate Relationship Building and Market Access by Businesses to Speed Technology Deployment

In its first phase, CERC actively engaged more than 150 partners, who helped drive innovation and ensure market acceptance of new or improved technologies. By creating a central role for partner engagement, CERC's collaborative platform actively encourages industrial business partners to provide strategic advice on clean energy deployment. Industry market leaders, top U.S. and Chinese research institutions, and world-class universities work closely within CERC partnerships to fast-track technology innovation and market entry. For example, Johnson Controls, a CERC partner in the U.S. BEE Consortium, is opening its new Asia-Pacific headquarters in Shanghai; the building will function as a "test bed" for CERC partners to advance clean energy technologies like integrated sensing and control networks and renewable energy systems. Partner interest and engagement continue

4

UTILITY MODEL PATENT APPLICATIONS IN CHINA BY U.S. PARTNERS

>$42M

IN COST-SHARE FROM U.S. PARTNERS

10

PROJECTS WITH COMPANIES DEMONSTRATING TECHNOLOGY

Evaluating algae for CO_2 capture in a real-world environment

CERC researchers from the University of Kentucky, ENN Group, and Duke Energy conducted several demonstrations of photobioreactors (PBRs) and analyzed the potential for using algal biomass to capture CO_2 emissions from power plants. At the same time, to better understand the cost dynamics of these technologies, researchers ran techno-economic analyses that influenced the design of the PBRs and helped make them more cost-efficient.

Based on the initial demonstrations and analyses, researchers determined that installation costs are a key factor in the overall system economics. Researchers then developed a next-generation 'cyclic flow' reactor, which reduces costs by optimizing tube spacing (making more efficient use of capital) and using a more affordable support frame. This radically new design, the 'cyclic flow' reactor, was prototyped, tested, and deployed at Duke Energy's East Bend Station. Researchers found this design to be more energy efficient, more productive, and less capital-intensive than its predecessor. Researchers further refined the technology to improve its operational stability and tested it under continuous operation for five months. The system produced more algal biomass in one growing season than had previously been grown over the course of the entire project.

This successful project illustrates the benefits of U.S. and Chinese CERC researchers engaging collaboratively, building on the strengths of each of its partners, and sharing data—particularly the results collected at the demonstration site.

to increase, and U.S. partner cost share is now at 60%—a strong indicator that partners find value in CERC research and the associated market opportunities.

The CERC model has successfully launched 15 products (including software) in U.S. and Chinese markets, and another 10 technologies are now being demonstrated. Active industrial advisory boards help ensure technology relevance to target markets and rapid market uptake. Collectively, the three consortia have benefited from the advice of 31 U.S. industrial advisory board members, who actively inform the research and commercialization process.

CERC's demonstration projects have helped to test and showcase clean energy technologies in a real-world environment (see box on facing page 18). Bringing technologies to market is a key indicator of CERC's success—as rapid market uptake can accelerate progress toward a clean energy economy (see box below).

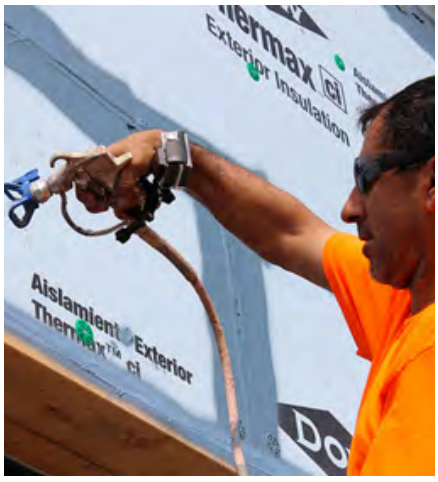
Accelerating market uptake of critical air barrier technologies

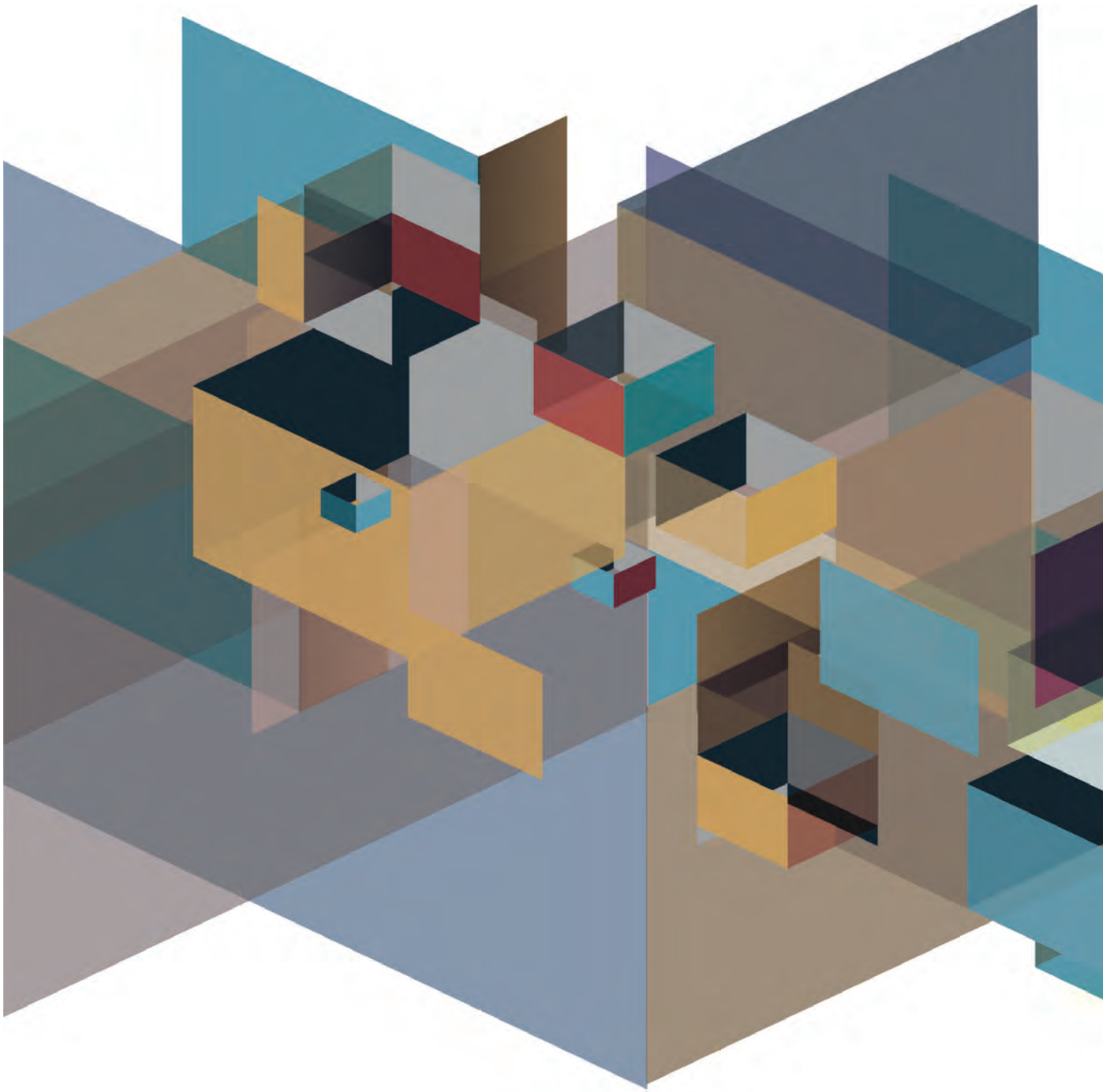
U.S. and Chinese researchers and industry partners leveraged complementary capabilities to produce two new products that can be easily installed to improve the airtightness of buildings: LIQUIDARMOR and 3M 3015.

Dow teamed with CERC researchers to develop a one-step, sprayable liquid flashing technology and launched the product as LIQUIDARMOR–CM and LIQUIDARMOR–RS, the commercial and residential versions, respectively. LIQUIDARMOR decreases air leakage by about 20%, and its rapid installation capability increases its cost-effectiveness. This seamless air and water sealant technology was demonstrated in several U.S. buildings and at CABR in Beijing. LIQUIDARMOR recently won the 2016 Gold Edison Award for Building Construction & Lighting Innovations, one of the most prestigious accolades honoring excellence in innovation.

3M collaborated with CERC researchers at ORNL to develop a primer-less, self-adhering membrane that entered U.S. markets as "3M 3015." This product is more durable and effective than prevailing air barrier technologies, adheres well to common building materials without priming, and can be installed twice as fast. It can be applied at low temperatures (~0°F) and is suitable for both new and existing residential or commercial construction. 3M and ORNL are installing 3M 3015 in demonstration buildings throughout the United States and at CABR.

Development of both products was facilitated by the complementary skills and resources of U.S. and Chinese researchers and industry partners. Industry gained greater access to top researchers and laboratory equipment and to rapidly expanding markets in both countries, while national laboratories benefited from industry expertise in the technology-to-market process and access to industrial facilities for demonstrating cutting-edge technologies.





2014-2015 Accomplishments: Delivering Results

CERC accomplished major objectives in a range of pursuits from October 2014 through December 2015. This includes technical accomplishments by CERC's three initial consortia:

- Advanced Coal Technology Consortium
- Building Energy Efficiency Consortium
- Clean Vehicles Consortium

In the same period, CERC launched two new consortia:

- Water and Energy Technologies (WET) Consortium
- Medium- and Heavy-Duty Trucks Consortium

Finally, CERC further strengthened two aspects of the Center that have become defining characteristics:

- Intellectual property protection
- Industry engagement

2014-2015 Accomplishments: Delivering Results

Advanced Coal Technology Consortium

Overview

Currently, coal is burned to generate about 30% of the electricity in the United States and about 63% of the electricity in China. Conventional coal use poses a challenge to meeting the ambitious greenhouse gas (GHG) emission reduction goals announced by the United States and China in November 2014. As these countries transition to a low-carbon economy, coal will continue to remain in the energy mix. CERC's Advanced Coal Technology Consortium (ACTC) conducts R&D in carbon capture, utilization, and storage (CCUS) technologies that will allow the continued use of coal as a strategic, economic, and secure fuel—while enhancing environmental protection.

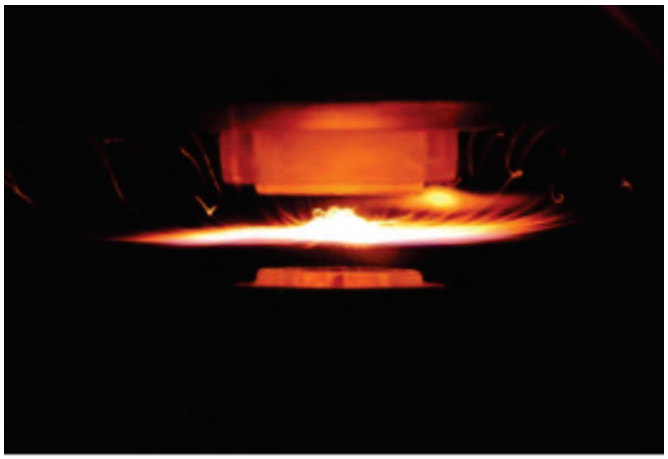
Highlights of ACTC's technical accomplishments during the final reporting period of Phase 1 (October 2014 through December 2015) are presented on the following pages. Numbers noted in parentheses refer to project numbers (for details go to www.us-china-cerc.org/Advanced_Coal_Technology.html).

Headquarters Locations for U.S. and Chinese ACTC Partners

ACTC Plans for Phase 2

In Phase 2, ACTC will shift its focus from bench-top and laboratory-scale projects to larger pilot projects, entailing deeper collaborative partnerships among U.S. and Chinese researchers and increased participation by the private sector. Activities will increasingly focus on scaling up and commercializing the technologies. ACTC aims to build upon its Phase 1 portfolio and deliver tangible outcomes in the following areas:

- *Advanced Power Generation*
- *Collaboration and Knowledge Sharing on a Large-Scale Demonstration Project*
- *CO_2 Utilization and Storage*
- *System Analysis and Modeling*



Advanced Power Generation

Efficiency improvements represent a cost-effective and practical approach to reduce CO_2 emissions in coal-fired power plants (CFPPs) in the near term. Research focuses on improving the efficiency, availability, and emissions performance of existing CFPPs; developing an advanced ultra-supercritical boiler system; and upgrading pulverizing systems for subcritical CFPPs.

- Developed a new computational fluid dynamics (CFD) model to better understand effects of coal type and particle size on boiler emissions. The new model improved predictive accuracy by using an in-house-developed Continuous Random Walk approach, which addresses time-averaged turbulence better than other CFD models (1.3)
- Demonstrated that interactions between coal particles and boiler walls are complex and sensitive to pre-set coefficients of restitution in CFD models (1.3)
- Determined that CFD-predicted results of particle physical properties are sensitive to boundary conditions and mesh generation, indicating that large eddy simulation turbulent modeling techniques, while more computationally intense, could help resolve remaining model discrepancies with experimentally measured results (1.3)

Clean Coal Conversion Technology

Clean coal conversion reduces emissions by producing co-products, like fuels and chemicals, in addition to generating power. CERC is conducting R&D on new coal-based cogeneration systems with CO_2 capture, including new coal-to-chemical cogeneration; new CO_2 capture processes; and cogeneration systems with combined pyrolysis, gasification, and combustion.

- Refined a slag flow model to simulate pressurized and staged oxy-coal combustion and used it to demonstrate that the moisture content of the coal feed is the single most significant factor in determining peak wall heat fluxes (2.1)
- Completed the design for a high-temperature rheometer to measure slag viscosity (2.1)
- Developed a bubbling bed reactor with submerged combustion as an alternative method to produce calcium carbide (CaC_2), which forms in the molten slag layer along the walls of an oxy-coal reactor. Unique applications of oxy-coal for the production of high-value chemicals like CaC_2 can improve the economics of oxy-coal technologies—a promising technology for CO_2 capture (2.1)
- Conducted coal gasification experiments in steam and combined CO_2/steam environments; found that steam gasification controls the rate of coal gasification (2.5)
- Completed residue gasification experiments and, based on the results, recommended use of a fluidized-bed system to gasify coal residue from the Powder River Basin in Wyoming (2.5)

CO_2 Capture Technologies

The primary technologies for capturing CO_2 emissions are designed for pre-combustion, post-combustion, or oxy-combustion use. Key barriers to large-scale uptake of these technologies are their high cost and negative impacts on plant efficiency. Research focuses on designing and optimizing commercial-scale IGCC systems with carbon capture; analyzing, testing, and demonstrating technologies for post-combustion capture integrated with sequestration at power plants; and developing, assessing, and optimizing oxy-combustion technologies.

- Identified and shared among industry partners the best practices and operational lessons learned from IGCC projects at Huaneng's GreenGen facility and Duke Energy's Edwardsport facility (3.2)
- Completed development of a homogeneous CO_2 hydration catalyst, which facilitates CO_2 capture from power plant effluent (4.3)
- Finished developing a CO_2 separation process using a third-generation DC-DC converter and verified the feasibility of energy recovery rates above 30% (4.5)
- Discovered a highly efficient mode for operating a capacitive deionization process, called extended voltage capacitive deionization, which improves salt removal and can reduce operating costs through improved efficiency over conventional methods (4.5)
- Designed and constructed a new, 1 atm, 30 kW, down-fired combustor to test aspects of staged, pressurized oxy-combustion technology (5.5)

CO_2 Sequestration Capacity

Meeting GHG reduction goals will require capturing and permanently storing CO_2 in a safe and cost-effective manner—even as the use of clean and renewable fuels increases. Research focuses on geologic storage in deep saline reservoirs, underground storage using enhanced oil recovery (EOR), enhanced coal bed methane recovery, and enhanced water recovery (EWR) methods.

- Developed a strategy to evaluate site characteristics and prioritize fields in China's Ordos Basin in terms of compatibility with CO_2 flooding techniques and an EOR/storage project (6.1, 6.2)
- Identified unique geologic challenges in the Ordos Basin as compared to the Rock Springs Uplift, a similar site in the United States (6.2)
- Evaluated the CCUS potential of Duke Energy's Gibson Station power plant using two approaches: a static geological resource assessment methodology and the new, integrated-system decision support tool SimCCUS (6.4)
- Assembled a U.S. team to support a new carbon storage project in China to study and monitor carbon storage using industrial CO_2 and advance a new EWR pilot project (6.6)

CO_2 Utilization with Algae

Using biofixation, microalgae can use the CO_2 emitted from power plants to generate energy sustainably. To lower the cost of this technology, ACTC researchers are screening algal strains, developing optimization strategies, conducting techno-economic analyses, and developing efficient post-processing technologies.

- Created low-cost, customized algae culture that could be scaled up (7.1)
- Increased the amount of algal biomass grown and harvested per unit volume in an improved cyclic reactor system (7.2)
- Designed small prototype lamella thickener to increase the efficiency of larger algae culturing operations and potentially improve algae attractiveness as a biopolymer feedstock (7.3)
- Conducted life-cycle assessment of new "cyclic flow" photobioreactor (PBR) system for a hypothetical 1 MW coal-fired power plant with 30% CO_2 capture and found that the system is carbon negative over its operational lifespan—the two biggest contributors to CO_2 emissions being the acquisition and recycling of the PBR tubes and the energy required to compress the flue gas for injection into the PBR (7.4)

Simulation and Assessment

Modeling and simulation methods can provide new insights on the feasibility of advanced coal technologies. ACTC focuses on assessing and optimizing the economics and operability of existing and novel carbon capture technologies.

- Developed process model and conducted dynamic simulations of a 10 megawatt (MW) CO_2 recompression Brayton cycle, which uses an additional compressor to improve cycle efficiency, to study both steady-state and dynamic performance. This research is essential to understanding the difficulties in operating such systems (8.1)
- Compared the performance of two controller types, proportional-integral-derivative (PID) and linear model predictive control (LMPC), for the integrated dynamic system of a supercritical pulverized coal plant with CO_2 capture. Found that LMPC provided superior stability and response time in controlling emission levels and corresponding CO_2 capture rates. Also developed a non-LMPC for further testing and comparison with PID and LMPC (8.2)

Building Energy Efficiency Consortium

Overview

Buildings account for about 40% of energy use in the United States and about 20% in China, and total floor space is expanding by about 2 billion square meters per year. Clearly, the sector presents an immense opportunity to improve energy efficiency and reduce CO_2 emissions.

The Building Energy Efficiency (BEE) Consortium is conducting high-impact research to improve the energy efficiency of new and existing buildings, increase indoor comfort, reduce GHG emissions, and integrate renewable energy resources. BEE fosters collaboration among researchers, industry experts, and policy makers to develop and successfully commercialize more efficient building technologies. BEE simultaneously seeks to influence policymaking to ensure that energy-efficient building technologies can have a sustainable impact in high-growth markets.

Highlights of BEE's technical accomplishments during the final reporting period of Phase 1 (October 2014 through December 2015) are presented on the following pages. Numbers noted in parentheses refer to project numbers (for details go to www.us-china-cerc.org/Building_Energy_Efficiency.html).

Headquarters Locations for U.S. and Chinese BEE Partners

BEE Plans for Phase 2

In its second phase, BEE's vision is to build on its foundational knowledge, technologies, skills, and relationships to accelerate development and deployment of very low-energy buildings in both countries—contributing to a potential 50% reduction in commercial building energy use, relative to a 2050 baseline. BEE plans to capture these benefits actively and passively in the following new areas.

- *Integrated Design, Construction, and Industrialized Building* will provide a platform for optimally integrating a wide range of standardized energy-saving features into pre-fabricated facades for new construction or existing building re-skins.
- *Control Commissioning and Data Mining* will develop and demonstrate more intelligent, accessible, and interactive sensing and control for commercial building energy systems.
- *DC Buildings and Smart Grid* will identify methods to enable DC buildings—avoiding potentially large losses from multiple conversions between DC and alternating current (AC) electricity.
- *Integrated Team on Policy and Market Research* will explore targets and build roadmaps for energy conservation in China and the United States; examine policies, markets, and technologies to inform policy making; identify and pilot financing mechanisms for commercial building retrofits; strengthen codes and standards through technology/policy impact assessments.
- *Indoor Environment Quality* will focus on HVAC and air quality, ensuring that new systems are efficient, safe, and comfortable.

BEE will continue joint work on demonstration projects and key building efficiency technologies and will develop roadmaps to commercialize products.

Building Design

BEE researchers examine the extent to which human behavior affects energy use in buildings and develop tools to comprehensively analyze the energy use and efficiency of fully integrated building systems, including design, operation, and behavior.

- Significantly improved a number of previously developed software tools to better characterize human behavior and quantify its impact on building energy performance (#1)
- Studied the energy performance of 51 high-performance buildings and identified an integrated approach to design, operations, and human behavior as the key to success. Piloted the Evaluation and Energy Reporting Protocol with the CABR demonstration building (#1)

Building Equipment

New and more energy-efficient building technologies and equipment (e.g., lighting, heating, ventilation, and cooling systems) need to be integrated with metering systems and optimized with management software to successfully penetrate the market. BEE researchers are testing the compatibility and efficiency of such integrated systems.

- Installed and tested a lighting control system to ensure its internal measurements accurately report data relative to external sensors. Used the test results to develop a guidance document supporting future direct data comparisons (#5)
- Concluded work on a model of the Nexajoule prototype chiller and validated model results. Demonstrated the chiller at the U.S. Department of Energy (DOE) Solar Decathlon in California. Tested the Tsinghua chiller from China and selected a U.S. location for its field demonstration (#8)

Distributed Energy and Renewable Energy Utilization

Renewable energy technologies can potentially convert buildings from energy consumers into net energy producers, making them part of a distributed generation system for the grid. To succeed, these technologies must first be integrated and optimized within the building's microgrid. Researchers are designing novel equipment and developing models to facilitate market uptake and effective use of these technologies.

- Commissioned a first-of-its-kind, flexible research platform for distributed ground-source heat pump systems and used it to characterize the performance of an innovative pumping system. Developed a new control strategy for the ground source integrated heat pump, which can reduce peak electric demand by up to 50% and avoid use of inefficient electric resistance heaters for water heating (#6)
- Provided research and support that was instrumental in establishing a new Chinese chapter of the International Ground Source Heat Pump Association (#6)
- Researched and developed two real-time, predictive control and optimization models to identify and address current energy issues in buildings. Developed a district-level optimization tool and tested it with various inputs and constraints (#10)

Whole Building

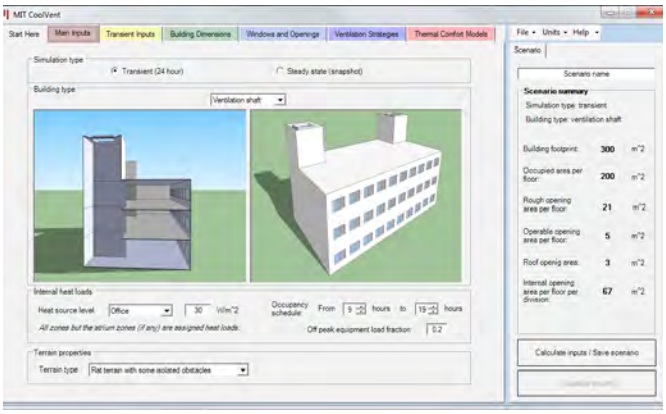
Buildings need to be analyzed as whole systems to realize their energy efficiency potential. Whole-building analysis involves the use of research, benchmarking, and modeling software to develop comprehensive, real-time strategies to reduce costs and peak loads. Wider use of building commissioning can boost energy efficiency by ensuring all equipment is properly sized and specified for the application.

- Completed revisions to an online version of the China Building Energy Benchmarking Tool, which provides a peer rating of energy performance for hotels, commercial offices, hospitals, and shopping malls. Used the tool to analyze data for 36 hotels, 2 office buildings, and a shopping mall. Completed a draft national-level China hotel energy performance database taxonomy, drawing on the U.S. DOE Building Performance Database taxonomy (#12)
- Completed development of automated commissioning algorithms and validated them through simulation. Published the first Chinese commissioning handbook (#7)

Policy and Market Promotion

Effective policy and market decision-making is essential to support the high market penetration of advanced building technologies. CERC researchers provide software tools and simulate future policy changes to help the United States and China implement the most effective building design standards.

- Developed the EnergyPlus building energy model for office buildings and shopping malls and conducted simulation to determine the cost-benefit performance of the new Chinese building standards (#9)
- Simulated the next version of the Chinese commercial code and compared its performance with that of the 2015 code to understand the improvement potential. Identified areas in which American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) requirements exceed those of the 2015 Chinese code and implemented those requirements in EnergyPlus (#9)



Building Envelope

Developing sealants and other air barriers to reduce energy leakage from buildings can yield significant energy savings. BEE is researching new insulation materials and modeling air leakage to assess impacts on energy use and indoor environments. Researchers are also designing novel cool roof materials and application methods.

- Assessed automated window shading technologies and an integrated control system for numerous energy-saving technologies. Defined a scalable system architecture for a room-level, real-time controller and implemented it in the building emulator (#2)
- Built and evaluated test walls for Dow's LIQUIDARMOR sprayable liquid flashing and 3M's 3015 primerless self-adhering membrane (#3)
- Demonstrated that widespread use of cool roofs could substantially cool the city of Guangzhou during heat waves. Results contributed to China's 2016 standard, which offers credits for public and residential buildings (#4)
- Continued cool roof natural exposure program in nine Chinese cities and completed accelerated testing and optimized formulation of 12 prototype white roof coatings. Synthesized a new cool roof particle coating that demonstrates better performance. Developed application methods to improve coating processes and properties (#4)
- Defined parameter effects in the CoolVent software tool to increase accuracy. Ran full optimization of a single room to help optimize control strategies. Simulated solar panel mounting effects on natural ventilation systems (#11)

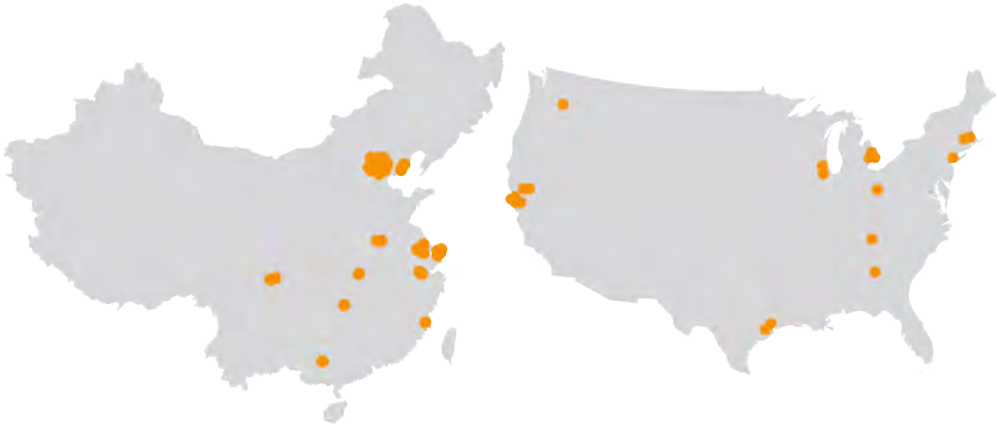
Clean Vehicles Consortium

Overview

As the world's top automobile markets and oil consumers, China and the United States recognize the pressing need to develop and deploy vehicles that are simultaneously cleaner, more efficient, safer, and more durable. Accelerated adoption of clean vehicles is essential to shift the United States and China toward low-carbon economies. The CERC Clean Vehicles Consortium (CVC) addresses this need and seeks to dramatically improve technologies that reduce oil dependence and increase fuel efficiency. CVC researchers focus on advancing and commercializing promising technologies that benefit both countries.

CVC's strategy includes conducting high-quality research in specific technology areas that could exert high impacts, strengthening and broadening collaborations with industry, leveraging existing platforms, and engaging with key stakeholders.

Highlights of CVC's technical accomplishments during the final reporting period of Phase 1 (October 2014 through December 2015) are presented on the following pages. Numbers noted in parentheses refer to project numbers (for details go to www.us-china-cerc.org/Clean_Vehicles.htm).



Headquarters Locations for U.S. and Chinese CVC Partners

CVC Plans for Phase 2

In its second phase, CVC will continue to identify and pursue collaborative research topics that have the potential to save energy by improving vehicle efficiency and reducing reliance on oil. Building on the first phase, CVC will streamline its research portfolio into four thrust areas:

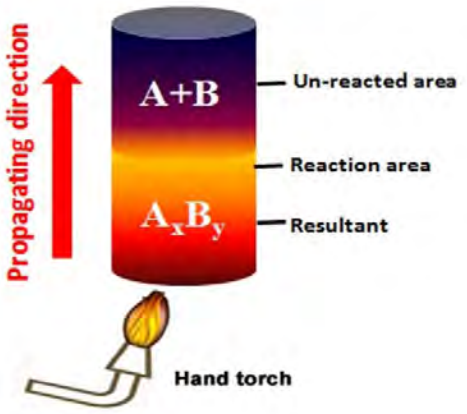
- *Advanced Batteries and Energy Conversion:* Develop safe and efficient, high-energy-density advanced battery chemistries and characterize their degradation
- *Vehicle Technologies:* Optimize electrified powertrains, novel energy conversion devices, and electric vehicle battery design and protection
- *Connected and Automated Vehicles*: Expand existing CERC research into a wider range of promising intelligent transportation system applications. Examples may include quantifying the energy impacts of automation and connection systems, maximizing plug-in electric vehicle (PEV) market penetration with advanced charging infrastructure, and evaluating potential impacts of shared mobility
- *Systems Assessment:* Conduct impact analyses and technology evaluations to inform consumer studies, PEV market prediction, policy assessments, and best practices

CVC works at the leading edge of clean vehicle technology—leveraging the expertise of its researchers, building true collaborations with industry partners, conducting cutting-edge research, and influencing policy.

Advanced Batteries and Energy Conversion

To reduce the cost of modern PEV battery systems and increase the deployment of clean vehicle technology, CVC conducts research to clarify battery degradation mechanisms, develops modeling tools for predicting performance and service lifetimes, and conducts basic R&D on high-energy battery chemistries.

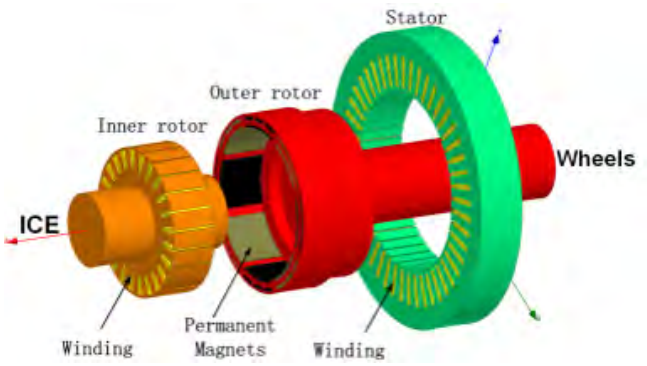
- Analyzed qualitative changes in the lithium-ion phosphate battery cathode as it degrades in situ (1.1.1)
- Validated a direct, non-destructive method for measuring lithium transport in batteries for several battery materials to enhance the accuracy of battery performance models (1.1.2)
- Demonstrated that adding fluorine to the electrolyte in lithium-air batteries can slow one key degradation mechanism and improve the battery life cycle (1.1.3)
- Manufactured and aged pouch-type battery cells for degradation studies. Validated excellent cell reproducibility, cyclability, and rate performance (1.1.4)
- Modeled the properties of sodium-air batteries, specifically researching the reasons for higher efficiency in sodium superoxide versus sodium peroxide battery chemistries (1.2.1)
- Studied oxygen loss in lithium-air battery chemistry to make the technology adaptable for commercial usage via improved cycle life, rate capability, and capacity/voltage retention over cycles (1.2.2)



Clean Combustion and Energy Conversion

Next-generation biofuels could provide a significant portion of transportation fuels in the United States and China. Market entry of these fuels can be accelerated through combustion research and the design, optimization, and control of exhaust after-treatments. In addition, thermoelectric devices can convert exhaust gas heat into electricity. Research focuses on cellulosic biofuels, understanding powertrain and after-treatment control systems, and developing novel thermoelectric materials.

- Provided fundamental insight into biofuel reactions in internal combustion engines by testing the oxidation of hexene isomers, which are used to represent biofuels, to more accurately describe low-temperature auto-ignition and fuel consumption (2.1)
- Characterized novel biofuels and created a model to better understand how biofuels behave in internal combustion engines under a wide range of operating conditions (2.2)
- Improved methodologies to optimize fuel efficiency and reduce emissions via powertrain and after-treatment controls in hybrid electric and diesel systems, integrating predictions of road grade and driver behavior (2.4)
- To utilize waste heat with thermoelectric materials, applied CERC research to self-propagating high-temperature combustion synthesis, then characterized and optimized the performance of various compounds (2.8)



Vehicle Electrification

This area seeks to improve the design and optimization of motors and power electronics, develop models for guiding the design of efficient powertrains in hybrid vehicles, and improve understanding of system integration technologies.

- Further developed a faster and more efficient computer tool for designing and modeling EV motors and used that tool to build and test an in-wheel motor in collaboration with Denso. Also optimized an ultra-capacitor and battery energy storage system for an electric bus (3.1)
- Improved a near-optimal powertrain energy management strategy (PEARS+) that enables fast prototype design and sizing—and potentially enables real-time predictive control. Completed case studies on a Toyota Prius and a power-split hybrid Ford F150, realizing multiple optimized scenarios for each (3.3.1)
- Characterized the causes and effects of unintended EV acceleration and developed a control scheme to detect and isolate such faults. Conducted off-vehicle bench testing for several failure scenarios (3.3.2)
- To improve algorithms for detecting a vehicle's battery health while it is connected to the grid, characterized the way manufacturing differences in battery cell capacity and resistance affect the module over time (3.4.1)

Advanced Lightweight Materials and Structures

Reducing a vehicle's gross weight can reduce its energy consumption, but balancing weight reduction with structural rigidity and crash safety in a multi-material structure has proven challenging. To enable use of low-cost and crashworthy lightweight materials, CVC works to develop and understand lightweight body manufacturing and design processes and to assess the integrity of lightweight EV structures.

- Completed the preliminary gateway adhesive testing program, enabling more accurate testing and modeling of the new hybrid material joining system (4.2)
- Tested The OhioState University's vaporized foil actuator process to weld aluminum alloys to steel in diverse size applications (4.3.2)
- Successfully validated simulated friction stir welding results with experimentally observed material distribution on a weld cross section (4.3.3)
- To more accurately model hybrid multi-material bonds, developed an understanding of limitations on optical techniques used in digital image correlation for testing bonded samples (4.4)
- Increased accuracy of the multi-material integration model by refining predictions of composite molding time; solved the multi-material body structure optimization problem using an algorithm developed in-house; improved topology optimization and an image-based decomposition strategy to integrate different materials into the workpiece (4.5)

Vehicle Grid Integration

To better understand interactions between EVs and the grid, CVC conducts activities to (a) assess the impact of EV charging on a large scale, (b) develop advanced strategies for controlling vehicle-grid interactions, and (c) analyze the potential of Intelligent Transportation Systems to optimize vehicle charging infrastructure and energy use.

- Created modeling simulations that accurately predict wear and tear on transformers due to fast-charging of electric vehicles (5.2)
- Demonstrated (via simulation) the ability of a new charging control algorithm that enables each EV to communicate with the grid to minimize charging cost based on a forecast electricity price profile—while accounting for local grid and battery effects (5.3)
- Developed and built a 3.3 kW EV wireless charging system with Denso, reaching 92.6% efficiency at a 150 mm gap distance. Won the best innovation design prize at the 2015 International Future Energy Challenge (5.4)

Energy Systems Analysis, Technology Roadmaps, and Policy

Large-scale deployment of PEVs requires understanding variations in energy sources, their impacts, and likely fuel and carbon policies. This area evaluates the life-cycle performance of EVs, develops technology roadmaps, identifies optimal fuel mix strategies, and develops strategies to accelerate EV deployment.

- Developed model to evaluate the energy performance of a dynamic, wireless highway charging system for PEVs and predict the minimum market share of all-electric cars required for the system to provide an advantage over standard plug-in charging (6.1)
- Assessed the feasibility of high market uptake of alternative fuel vehicles focusing on: charging station placement, urban ride sharing, and float car data to estimate real-time traffic flow (6.2)
- Forecast how different EV penetration rates could affect China's fleet and electric grid emissions from 2015 to 2050 (6.4.1)
- Improved electric grid model for evaluating the sustainability of EVs by incorporating Plexos, a high-performance power simulation system (6.5.2)
- Finalized a life cycle model that compares eight recycling methods for aluminum and steel hoods. Worked on methodology that uses exergy content of material and energy flows to fill the recycling gap in current resource depletion literature (6.5.1)

Water and Energy Technologies Consortium

Water and energy systems are heavily interdependent. Water is required in many phases of energy and power production; it is used to generate hydropower, irrigate biofuel crops, and cool power plants. Likewise, energy is required to extract, treat, convey, and deliver water of appropriate quality for diverse human uses or for return to the environment.

Headquarters Locations for U.S. and Chinese WET Partners

As the impacts of climate change become more apparent and energy needs rise, there is growing awareness that water-energy interactions must be managed in an integrated and proactive manner. Higher temperatures and changing precipitation patterns could decrease water availability. Water scarcity, supply variability, and related uncertainties could adversely affect energy systems. In addition, population growth in arid areas—such as the Southwestern United States and Northern China—is likely to continue, increasing demand and stresses on both energy and water systems. Innovative technologies at the nexus of energy and water could significantly improve the efficient use and management of water in energy systems and, similarly, the use and management of energy resources in water systems.

In November 2014, the Presidents of the United States and China announced a new CERC research consortium to address the challenges and opportunities of Water and Energy Technologies (WET). CERC's unique capabilities to develop cutting-edge technologies through true bilateral R&D are expected to benefit both countries.

In August 2015, the U.S. DOE selected the University of California, Berkeley, as the lead for the U.S. CERC WET consortium. In a parallel effort, China's Ministry of Science and Technology (MOST) announced its CERC WET lead as the Research Institute of Petroleum Exploration & Development (RIPED). In December 2015, WET consortium leaders from the United States and China met with CERC representatives from DOE and MOST in Beijing to discuss next steps for collaborative research. During the first months of 2016, the U.S. and China teams worked together to develop the WET Joint Work Plan and Technology Management Plan (TMP) that will form the foundation for partnerships with industry leaders.

CERC WET research will focus on the following areas:

- Water Use Reduction at Thermoelectric Plants
- Treatment & Management of Non-Traditional Waters
- Improving Sustainable Hydropower Design and Operation
- Climate Impact Modeling, Methods, and Scenarios to Support Improved Understanding of Energy and Water Systems
- Data and Analysis to Inform Planning, Policy, and Other Decisions

Medium- and Heavy-Duty Trucks Consortium

Medium- and heavy-duty trucks are the backbone of freight transportation systems and vital to economic growth in the United States and China. Increasing the fuel efficiency of these trucks can yield numerous benefits for both countries, including reduced GHG emissions, improved air quality, reduced dependence on oil, and lower transport costs. Globally, trucks are the second largest source of GHG emissions in the transportation sector. In the United States, medium- and heavy-duty trucks together haul nearly 73% of domestic freight tonnage and account for 4% and 18%, respectively, of energy use in the transportation sector. In China, precise percentages are unknown but are estimated to be higher.

Average efficiency in trucks has improved over time, although performance varies considerably across classes of trucks and even among individual vehicles within a class. Opportunities are plentiful to increase truck fuel efficiency through advancements in powertrains, aerodynamics, and controls.

To accelerate the development and deployment of technologies that will increase the fuel efficiency of medium- and heavy-duty trucks, the Presidents of the United States and China announced a fifth CERC consortium in September 2015. This new consortium will focus on developing cost-effective measures to improve the on-road freight efficiency of these trucks by more than 50% compared to the 2016 baseline. Research will focus on:

- Advanced Internal Combustion Engine/Powertrain Systems
- Energy Management (System-Level Efficiency Improvements)
- Hybrid Electric Powertrains
- Other Key Truck Technologies
- Applied Research, Testing, and Evaluation

CERC is currently identifying lead partners for this consortium; an announcement is expected in late 2016.

Intellectual Property

The CERC intellectual property (IP) framework helps to build trust and foster knowledge exchange among participants, as required for true collaboration. CERC's IP education and training program helps participants better understand the framework and relevant IP laws and regulations in the two countries. Accomplishments over the past year include the following.

Researchers' Guide to IP and Technology Transfer

This Guide explains key issues related to CERC project IP protection, development, commercialization, and marketing. It provides an overview of the technology transfer process in layman's terms and addresses questions related to the commercial development of inventions that may result from CERC research. The Guide, which covers both Chinese and U.S. IP law, is presented in a "question & answer" format designed for non-lawyers. Available in English and Chinese, the Guide helps U.S. and Chinese researchers navigate the often complex IP issues in both countries.

Training Session

CERC conducted a training session in Wuhan, China, to provide an overview of the CERC IP framework and expose participants to the broad range of IP issues and strategies that may be encountered in the context of CERC research. IP experts, including leading practitioners from U.S. and Chinese law firms, academics from Huazhong University of Science and Technology (HUST), and technology transfer experts from Tsinghua University, offered insights into patent strategy, IP licensing strategy and practice, the patent application process, and technology transfer for academic institutions. Officials from China's MOST, the U.S. Embassy in China, the U.S. Patent and Trademark Office, and China's State Intellectual Property Office discussed their organizations' efforts to enhance U.S.-China cooperation on technology innovation. The two-day pilot session was well attended and deemed a resounding success. Participants congratulated CERC and highlighted the critical gap now filled by a curriculum on CERC's IP framework and continuing IP education for CERC researchers.

Event and Webcast

CERC organized an event and webcast to update CERC researchers on rapidly evolving IP issues and provide concrete examples of IP management and protection in China. Experts emphasized the need for companies to be proactive when conducting business in China—establishing robust corporate IP strategies and preventive measures to avoid the need for litigation. Experts also discussed recent improvements in IP protection policy and related issues.

Key Findings on the IP Needs of Chinese CERC Partners

CERC's IP program offers technical assistance, training, and resources to help CERC researchers protect their IP. To identify existing IP knowledge gaps and better focus technical assistance to Chinese partners, the program conducted a survey of the leaders or chief IP officers of the lead CERC institutions in China. Key findings, which are now helping to shape future work plans of the IP program, are as follows:

- About half of the experts that engage with CERC on intellectual property issues have technical rather than legal backgrounds.
- The main areas in which researchers need support are IP contract drafting and consulting, followed by training and policy interpretation.
- Top training needs include the following:
  - direct comparisons between IP law in China and in the United States
  - patent filing processes in the two countries
  - IP management for joint research projects
  - IP contract drafting
  - translation of the TMP framework agreement to a project level.

IP Plans for Phase 2

Senior government officials in the United States and China have recognized the CERC IP framework as a key factor in CERC's success as a bilateral partnership. As CERC embarks on its second phase, IP will remain a critical enabling feature of CERC's collaborative innovation environment. For Phase 2, the IP program is planning the following actions:

- Identify coordinators for each consortium to make sure that all researchers have easy access to resources and guidance on IP-related issues and to enable greater engagement at a project level
- Strengthen training by conducting more IP education and training sessions in universities, modeled on the pilot session held at HUST in Wuhan, China, in November 2015
- Provide a platform, such as a CERC-wide IP workshop, that will allow CERC researchers to explore IP issues on a regular basis
- Develop additional educational materials, such as a best practices guide for drafting IP contracts
- Establish an online knowledge-sharing platform with IP training videos and other resources for researchers
- As needed, facilitate access to legal advice or assistance from outside resources
- Pilot innovative solutions to enable and promote joint innovation, emphasizing solutions that help researchers efficiently create, share, protect, and manage IP
- Conduct additional surveys of CERC participants to better understand their needs and the challenges to joint collaboration
- Share the CERC IP framework as a model for other U.S.-China joint programs and other bilateral partnerships

Industry Engagement

Industry participation is a major factor in CERC's success. Industry partners provide seasoned expertise, essential financial and technology resources, and knowledge of markets to help move technologies toward commercialization. By participating in CERC, industry partners gain access to world-class scientists and engineers at top research institutions, use of large-scale demonstration facilities, insight into policymaking in both countries, and the ability to reach new partners and expanded markets in the United States, China, and around the world. Industry partners are aware that their engagement in CERC is recognized at the highest levels of both governments. They understand that this recognition reflects the importance of their work and other contributions toward national goals. CERC provides industry with a launch pad to test, demonstrate, commercialize, and scale up innovative technologies—leveraging their investments and maximizing returns.

In its second phase, CERC welcomes new industrial partners in all five of its Phase 2 consortia. New consortium partners must meet the following criteria:

- Support the mission of CERC and the vision and goals of the respective CERC Consortium
- Support projects that align with CERC areas of research
- Bring additional capacity or expertise to the projects
- Agree to be bound by the same obligations as existing members
- Agree to the provisions of the CERC Protocol and Technology Management Plans

Prospective members are encouraged to apply to their respective country's CERC Consortium Director. Contact information may be found at www.us-china-cerc.org/How_to_Join_CERC.html.

CERC Partners

Advanced Coal Technology Consortium

Huazhong University of Science and Technology (HUST) (China Consortium lead) • **West Virginia University (WVU)** (U.S. Consortium lead) • Alstom/GE • Arch Coal • Beijing Baota Sanju Energy and Technology Company • China Huaneng Group Clean Energy Research Institute • China Huaneng Group Power International, Inc. • China National Petroleum Corporation • China Power Investment Corporation • China University of Mining and Technology • Chinese Academy of Sciences, Institute for Rock & Soil Mechanics • Chinese Academy of Sciences, Institute of Geology and Geophysics • Chinese Academy of Sciences, Research Center for Energy & Power • Duke Energy • ENN (XinAo Group) • Harbin Institute of Technology • Illinois State Geological Survey • Indiana University • Jupiter Oxygen Corp • Lawrence Livermore National Laboratory • Los Alamos National Laboratory • LP Amina • National Energy Technology Laboratory • Peabody Energy • Shaanxi Yanchang Petroleum Group Co., Ltd. • Shanghai JiaoTong University • Shanxi International Energy Group • Shenhua Group • Southeast University • Southern Company • Stock Equipment • Tsinghua University • University of Kentucky • University of Wyoming • Washington University in St. Louis • World Resources Institute • Zhejiang University

Building Energy Efficiency Consortium

Lawrence Berkeley National Laboratory (LBNL) (U.S. Consortium lead) • **Ministry of Housing and Urban-Rural Development (MOHURD)** (China Consortium lead) • 3M • Anhui Roba Energy Saving Technology • BASF • Beijing Ever Source Science & Technology Development • Beijing Huaqing Geothermal Development • Beijing Huayi Leye Energy Service • Beijing Lampower Photoelectric • Beijing Persagy Energy Saving Technology • Beijing Zhongchengke Green Building Technology • Bentley Systems Incorporated • C3 Energy • China Academy of Building Research • China Lanp Electrical • China Society for Urban Studies • Chint Solar Co., Ltd. • Chongqing University • Chongqing Zhonghai Industry • CISDI Engineering • Citibank • ClimateMaster • CSUS Green Lighting Science & Technology Research Center • Dasheng Roller Shutters • Dongguan Vanke Building Technology Research • Dow Chemical Company • East-West Control Group • Energy Foundation, China Sustainable Energy Program • ENN Group • Forest City • Guangzhou Zhengli General Electric • Himin Solar Energy Group • ICF International • Institute for Market Transformation • Jiangsu Aide Solar Energy Technology • Jiangsu Disimai Ground Source Heat Pump Air Control • Jiangsu Refrigeration & Heating Saving Equipment • Jiangxi Lattice Lighting • Jilin Kelong Building Energy-Saving Technology • Johnson Controls • Landsea Group • Lend Lease • LH Technology • Liaoning Solar Energy R&D Co., Ltd. • Lumen Cache • Lutron Electronics • Massachusetts Institute of Technology • Nanjing Fullshare Energy Technology • Nari Technology Development • Natural Resources Defense Council • New Building Institute • Nextek Power Systems • Oak Ridge National Laboratory • Precast/Prestressed Concrete Institute • Rocky Mountain Institute • SAGE Electrochromics • Saint Gobain • Shanghai Convertergy Energy Technology • Shanghai Fuka Construction & Engineering • Shanghai Futian Air Conditioning Equipment • Shanghai Qingying Industrial Shares • Solatube CECIC Daylight Technology • TelChina (Shandong) Co., Ltd. • Tianjin University • Tongguang Jiangong Group • Tongji University • Tsinghua University • United Technologies Corporation • University of California, Davis • Walt Disney Imagineering • WattStopper • Wuxi Suntech Power • Xinghua Green Industry International Low Carbon Technology Development • Xinjiang Green Refreshing Angel Environment Technology • Yingli Energy • Zhejiang Dun'an Artificial Environmental Equipment • Zhongji Yuanxiong Energy Storage Technology • Zhuhai Singyes Green Building Technology

Clean Vehicles Consortium

Argonne National Laboratory (U.S. Consortium lead) • **Tsinghua University** (China Consortium lead) • A123 Systems • Aramco Services • BAIC BJEV • Beihang University • Beijing Institute of Technology • Beijing SinoHytec • Brookhaven National Laboratory • California Energy Commission • CALSTART • Changan Automobile Company • Changzhou ECTEK Automotive Electronics Limited • China Automotive Engineering Research Institute Co., Ltd • China Automotive Technology & Research Center • China Electric Power Research Institute • China Potevio • Chinese Academy of Sciences, Institute of Electrical Engineering • CITIC GuoAn Mengguli • ClimateWorks and Energy Foundation • Contemporary Amperex Technology Co., Limited • Delphi • Excellatron Solid State • Farasis Energy • Geely Group • GM • Hefei Guoxuan High-Tech Power Energy • Hunan University • The International Council for Clean Transportation • JAC Motors • Jiangsu Huadong Institute of li-ion Battery • Jing-jin Electric Co., Ltd. • Keypower • Massachusetts Institute of Technology • Microvast • North China Electric Power University • Oak Ridge National Laboratory, Energy and Transportation Science • The Ohio State University • Pacific Northwest National Laboratory • SAIC Motor • Shanghai Electric Vehicle Public Data Collection, Monitoring and Research Center • Shanghai General Motor Muling • Shanghai International Automobile City • Shanghai Jiao Tong University • Suzhou Automotive Research Institute of Tsinghua University • Technical Institute of Physics and Chemistry of Chinese Academy of Sciences • Tianjin Lishen Battery Joint-stock Co., Ltd • Tianjin University • Tongji University • University of California, Davis • University of Michigan • Wanxiang • Wanxiang America Corporation • Wuhan University of Technology

Water and Energy Technologies Consortium

Research Institute of Petroleum Exploration & Development (RIPED) (China Consortium lead) • **University of California, Berkeley** (U.S. Consortium lead) • Asia-Europe Water Resources Research and Utilization Center • California Energy Commission • China Institute of Water Resources and Hydropower Research • China Power Engineering Consulting (Group) Corporation • China Three Gorges Corporation • China University of Mining and Technology, School of Resource and Earth Science • China Yixing Industrial Park for Environmental Science & Technology • Chinese Academy of Sciences, Institute of Engineering Thermophysics • Dano (Beijing) Oilfield Services Co., Ltd • Energy Foundation • General Electric Company • Glacier Technologies • Guodian New Energy Technology Research Institute • Hunan Yongqing Environmental Science & Technology Co., Ltd • The Institute of Seawater Desalination and Multipurpose Utilization • International Applied Energy Technology Innovation Institute • Lawrence Berkeley National Laboratory • National Development and Resource Commission, Energy Research Institute • North China Electric Power University • Peking University Water Center • Power Construction Corporation of China • Shanxi Yanchang Petroleum Co., Ltd • Shenhua Group • Southern California Edison • Southern California Gas Company • Stockholm Energy Institute • Tsinghua University, School of Environment • University of California, Davis • University of California, Irvine • University of California, Los Angeles • University of California, Merced • University of California, Office of the President • Walt Disney Imagineering • Yalongjiang River Basin Hydropower Development Co. Ltd

Next Steps

Bold climate commitments by the United States and China require both countries to move rapidly toward a clean energy economy. CERC's unique framework for bilateral partnership has made it uniquely suited to help both countries meet their respective goals—and address the increasingly urgent need to reduce global carbon emissions as quickly as possible on a grand scale.

CERC participants recognize the importance of immediate climate action. A careful review of lessons learned during Phase 1 has informed the ambitious goals and strategic shifts planned for CERC Phase 2. Key shifts in CERC activities are designed to maximize the productivity and impacts of available resources and partnering arrangements—and help achieve the scope of market transformation required to mitigate the worst impacts of climate change.

Backed by strong financial support (see table below), CERC has set the bar high for its second phase. Its new research portfolio will emphasize ambitious, creative, and bold projects that require joint research and focus on applied R&D to obtain significant near-term market impacts. CERC will strengthen and broaden its teams of researchers and industrial partners, closely align projects to strategic goals, and more widely disseminate research findings and other project outcomes. As exceptionally promising technologies emerge, CERC may focus more resources on a smaller number of large projects that could truly disrupt existing markets and deliver powerful clean energy solutions.

Multi-Year Bilateral Funding Plan for CERC's Second Phase

Research Consortium	U.S.		China	Total Project Funding
	DOE	Partners	MOST & Partners	
Advanced Coal Technology Consortium*	$12.5M	≥ $12.5M	$25M	$50M
Clean Vehicles Consortium*	$12.5M	≥ $12.5M	$25M	$50M
Building Energy Efficiency Consortium*	$12.5M	≥ $12.5M	$25M	$50M
Water and Energy Technologies Consortium*	$12.5M	≥ $12.5M	$25M	$50M
Medium- and Heavy-Duty Trucks Consortium	$12.5M	≥ $12.5M	$25M	$50M
*Funding has been awarded for the five-year period, 2016–2020			Planned	≥ $250.0M

M: million

Appendices

Image Captions

Listed below are captions for images used throughout the Annual Report. Unless otherwise indicated, the sequence of the images is from left to right, top to bottom.

Cover

Chinese CERC partner, ENN, demonstrates a microalgae approach for CO_2 utilization.

The Xing Ye Building (shown in design rendering) in Zhuhai, China, is a demonstration building for CERC-BEE technologies.

CERC researchers at The Ohio State University, United States, are developing an electric vehicle charging station as one component in a microgrid testbed.

CERC WET's research portfolio includes an array of novel research projects to reduce water consumption, energy use, and carbon dioxide emissions from thermoelectric plants, including natural draft cooling towers (pictured).

Highly efficient medium- and heavy-duty trucks are the focus of CERC's fifth consortium.

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Sprayable liquid flashing technology, developed by CERC partners ORNL and Dow Chemical, reduces installation costs and improves sealing.

A battery anode passes through the drying zone of the coating line at the University of Michigan Battery Fabrication and Characterization User Facility in the United States.

CERC researchers simulated post-combustion capture processes at Huaneng's Shidongkou power plant in Shanghai, China (pictured), and applied them at Duke Energy's Gibson plan in Indiana, United States.

Page 6

CERC researchers shared best practices learned through the IGCC processes at Huaneng's Greengen facility in China (pictured) and Duke Energy's Edwardsport facility in the United States.

Page 8

Duke Energy's Gibson plant, in Indiana, United States, where the simulation of the Shidongkou plant's post-combustion capture process was applied.

A 3-MW Full Chain System oxyfuel combustion unit is shown at the Huazhong University of Science and Technology (HUST) in China.

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A first-of-its-kind techno-economic analysis developed by CERC researchers estimates the potential to store CO_2 in deep saline reservoirs associated with enhanced oil recovery in the Ordos Basin, China.

A 3D structural model for the Tianjin GreenGen vicinity in China was generated by a joint CERC team using available data.

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Performance of low-emittance windows with manually operated roller shades (left) are compared to automated switchable electrochromic windows (right) in the Saint-Gobain Research Shanghai building.

CERC researchers in China conduct natural exposure trials on a cool roofing product.

Page 11

The interior of a ground source emulator at ORNL's flexible research platform for distributed ground source heat pump systems.

A range of CERC building technologies are being demonstrated at the China Academy of Building Research (CABR) in Beijing, China.

Page 12

CERC scientist at the University of Michigan Battery Lab put an 18650 format battery through a cycling test.

The University of Michigan Battery Fabrication and Characterization User Facility (pictured) allows researchers to create prototype batteries. By characterizing these batteries with known material specifications, the state of charge models can be accurately validated.

Page 13

A Spark Plasma Sintering facility enables the synthesis of thermoelectric materials.

A wireless charging prototype was constructed by CERC researchers at the University of Michigan, United States.

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China President Xi Jinping (left) and U.S. President Barack Obama (right) attend a welcome ceremony at the Great Hall of the People in Beijing on Nov. 12, 2014. Photo credit: U.S. Department of State.

U.S. Energy Secretary Moniz and China's Minister of Science and Technology Wan participate in a CERC Steering Committee meeting in Washington, D.C., in June 2015.

U.S. Ambassador Baucus, U.S. Energy Secretary Moniz, China Minister of Science and Technology Wan and Vice Minister Cao, and Chief Planner Tang attend a CERC meeting at the Ministry of Housing and Urban-Rural Development in Beijing in July 2014.

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Participants discuss CERC IP sharing and protection at a workshop in Haikou, China, in March 2012.

Shoabin Zhu from the intellectual property law firm Finnegan, Henderson, Farabow, Garrett and Dunner attended a joint training on CERC IP held at HUST in China in November 2015.

Participants take notes at the Joint Training on IP at HUST in China in November 2015.

Professor Yu Xiang of HUST and Stacy Baird of US-China Clean Energy Forum participated in the joint training on IP at HUST in China in November 2015.

Participants attend a CERC IP workshop.

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A 'cyclic flow' reactor design operates at Duke Energy's East Bend Station.

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A worker installs 3M's 3015 primer-less, self-adhering membrane.

LIQUIDARMOR is easily applied to a demonstration building in Illinois, United States.

Dow teamed with CERC to develop a one-step, sprayable liquid flashing technology to improve building energy efficiency.

Page 23

CERC researchers examine particle behavior during flame penetration in coal combustion.

CERC researchers analyzed this CTC reactor, which was designed and patented by CERC partner LP Amina to produce calcium carbide from coal and limestone.

Page 24

CERC researchers conducted an experimental test to characterize the oxy-combustion of coal under various conditions at a 1 MWt oxy-combustion furnace at Washington University in St. Louis, United States.

CERC researchers monitored an industrial CO_2 injection station in China.

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A seeded 'serpentine flow' photobioreactor is shown at Duke Energy's East Bend Station in the United States.

Scientists researching a thermal-to-electric power conversion technology in a configuration called the recompression closed Brayton cycle. Photo credit: Sandia National Laboratories

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The headquarters of the Shenzhen Institute of Building Research (IBR), a CERC BEE partner, is a model of sustainable design.

The Nexajoule chiller was demonstrated at the 2015 U.S. DOE Solar Decathlon in California.

Page 28

Ground source heat pumps have the potential to dramatically lower energy use in buildings.

The China Building Energy Benchmarking Tool provides a peer rating of energy performance for hotels, commercial offices, hospitals, and shopping malls.

Page 29

The Chinese Building Energy Efficiency standard (left) and the ASHRAE Energy standard for Buildings (right) help with the implementation of energy efficient building designs.

Climate modeling indicates widespread deployment of cool roofs could lower mid-day summer air temperatures in Guangzhou, China, by about 1° C.

Page 31

A Li-Ion pouch cell battery is produced at the University of Michigan Battery Lab.

A schematic shows self-propagating high-temperature combustion synthesis, a process for producing thermoelectric materials for use in converting exhaust gas into electricity.

Page 32

A schematic show an electric variable traction-transmission machine and drive.

Specimens of spot-welded coupons were tested for use in light-weighting vehicles.

Page 33

CERC researchers validated fault-tolerant control algorithms for The Ohio State University's EcoCAR2 PHEV.

Electric vehicle charging infrastructure is a critical enabler in the widespread use of electric vehicles. Photo Credit: NREL/Mike Simpson

Page 34

CERC WET's R&D portfolio includes methods to reduce water consumption in hybrid forced-draft cooling towers (pictured). Photo credit: Cenk Endustri

Page 35

CERC aims to improve the fuel efficiency of medium- and heavy-duty trucks, like the SuperTruck (pictured) developed by DOE and its industry partners.

Inset: The CERC trucks team gathered at a joint initial meeting in China in December 2015.

Page 36

Associate Counselor Cai Jianing of China's MOST delivers a presentation at a joint training session on IP at HUST in China in November 2015.

DOE held a webcast on the IP challenges and opportunities of conducting business in China in Washington, D.C., in July 2015.

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CERC BEE partners examine advanced building technologies at a demonstration site in China.

CERC BEE held a workshop on building commissioning in China.

Acronyms and Notations

AC	alternating current
ACTC	Advanced Coal Technology Consortium
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BEE	Building Energy Efficiency Consortium
CABR	China Academy of Building Research
CaC_2	calcium carbide
CCUS	carbon capture, utilization, and storage
CERC	Clean Energy Research Center
CFD	computational fluid dynamics
CFPP	coal-fired power plant
CO_2	carbon dioxide
CVC	Clean Vehicles Consortium
DC	direct current
D.C.	District of Columbia
DOE	Department of Energy
EOR	enhanced oil recovery
EV	electric vehicle
EWR	enhanced water recovery
GHG	greenhouse gas
GHX	ground heat exchanger
GSHP	ground source heat pump
HUST	Huazhong University of Science and Technology
HVAC	heating, ventilation, and air conditioning
IBR	Institute of Building Research
IGCC	integrated gasification combined cycle
IP	intellectual property
LBNL	Lawrence Berkeley National Laboratory
LLNL	Lawrence Livermore National Laboratory
M	million
MOHURD	Ministry of Housing and Urban-Rural Development
MOST	Ministry of Science and Technology
MW	megawatt
ORNL	Oak Ridge National Laboratory
PBR	photobioreactor
PEV	plug-in electric vehicle
PID	proportional-integral-derivative
R&D	research and development
RIPED	Research Institute of Petroleum Exploration & Development
SHS	self-propagating, high-temperature combustion synthesis
SOH	state of health
TMP	Technology Management Plan
U.S.	United States
WET	Water and Energy Technologies Consortium

CERC Executive Leadership

Steering Committee Members

U.S.

Ernest Moniz
Secretary
U.S. Department of Energy

China

Wan Gang
Minister
China Ministry of Science and Technology

To Be Determined
China National Energy Administration

Chen Yiming
General Engineer
China Ministry of Housing and Urban-Rural Development

Secretariat

U.S.

Jonathan Elkind
Assistant Secretary for International Affairs
U.S. Department of Energy

Robert C. Marlay
U.S. CERC Director
U.S. Department of Energy

Alan Yu
Acting Deputy Assistant Secretary
Asia and the Americas
U.S. Department of Energy

Alex McLean
U.S. CERC Program Specialist
U.S. Department of Energy

China

Yin Hejun
Vice Minister
China Ministry of Science and Technology

Cai Jianing
Associate Counsel
China Ministry of Science and Technology

To Be Determined
China National Energy Administration

Han Aixing
Deputy Director General
China Ministry of Housing and Urban-Rural Development

Jiang Dehua
Director
China Ministry of Science and Technology

Advanced Coal Technology Consortium

U.S.

James Wood
Director
West Virginia University

Qingyun Sun
Collaboration Manager
West Virginia University

Sam Taylor
Operations Manager
West Virginia University

China

Zheng Chuguang
Director
Huazhong University of Science and Technology

Xu Shisen
Chief Engineer
Huaneng Clean Energy Research Institute

Yao Qiang
Chief Scientist
Tsinghua University

Building Energy Efficiency Consortium

U.S.

Nan Zhou
Director
Lawrence Berkeley National Laboratory

Rick Diamond
Deputy Director
Lawrence Berkeley National Laboratory

Yuan Yao
China Program Director
Lawrence Berkeley National Laboratory

Carolyn Szum
Operations Manager
Lawrence Berkeley National Laboratory

China

Liang Junqiang
Director
Science and Technology Center
China Ministry of Housing and Urban-Rural Development

Jiang Yi
Technical Director
Tsinghua University

Jiang Lihong
Deputy Director
China Academy of Building Research

Peng Chen
Program Manager
Science and Technology Center
China Ministry of Housing and Urban-Rural Development

Clean Vehicles Consortium

U.S.

Don Hillebrand
Director
Argonne National Laboratory

Michael Wang
Deputy Director
Argonne National Laboratory

Khalil Amine
Deputy Director
Argonne National Laboratory

Yan Zhou
Operations Manager
Argonne National Laboratory

China

Ouyang Minggao
Director
Tsinghua University

Wang Hewu
Deputy Director
Tsinghua University

Qiu Xinping
Deputy Director
Tsinghua University

Du Jiuyu
Operations Manager
Tsinghua University

Water and Energy Technologies Consortium

U.S.

Ashok Gadgil
Director
University of California

Scott Samuelsen
Deputy Director
University of California

Soroosh Sorooshian
Deputy Director
University of California

Carolyn Remick
Operations Manager
University of California

China

Liu He
Director
Research Institute of Petroleum Exploration & Development

Zhu Ronggai
China National Petroleum Corporation Representative

Wang Jianhua
Deputy Director
Institute of Water Resources and Hydropower Research

Bao Shujun
Secretary-General
Institute of Water Resources and Hydropower Research

U.S.–China Clean
Energy Research Center
中美清洁能源联合研究中心